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Piezoelectrically driven micro-lens out-of-plane actuation

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Abstract

This paper presents the design, fabrication and testing of a piezo-electrically driven actuator system for out-of-plane actuation of a micro-lens. The system consists of a micro-lens holding platform symmetrically supported by eight piezo-electrically driven actuators. The piezo-electrical actuator is a 900µm long multilayer structure consisting of Si (4µm)/SiO_2(1µm)/Ti(0.015µm)/Pt(0.135µm)/PZT(1.5µm) and inter-digitated Ti(0.015µm)/Pt(0.135µm) top electrodes. It is connected to the micro-lens holding platform through a 600µm long 4µm thick silicon structure. The actuation system has been successfully fabricated using bulk micro-machining with a 600µm glass microsphere lens mounted, and tested. The device demonstrated about 37µm out-of-plane deflection using 60VDC.

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Keywords: Piezoelectric actuation;inter-digitated electrodes;silicon micromachining;out-of-plane actuation;micro-lens;

1. Introduction

Precise movement of micro-lens in the Z-direction (out-of-plane) is a desirable function in many micro-opto-electro-mechanical systems (MOEMS) such as miniaturized microscopy, and cameras. In miniaturized microscopes, out-of-plane movement can be used to change the focal plane of the focused laser beam along the optical axis during the 2-D raster scanning to enable 3-D raster scanning. A stack of micro-lenses with each having out-of-plane movement in the optical axis is required to realize miniaturized cameras. The actuation systems that have been used for such application are so far based on thermal [1, 2] or electrostatic [3] mechanism. Although the thermal actuation operates at low voltage, it suffers from slow response time and large power consumption. On the other hand, electrostatic actuation requires large actuation voltage despite fast response and low power consumption.

In order to combine the advantages of both thermal and electrostatic actuation, that is fast response time, low power consumption, and lower operating voltage, we present in this paper a piezo-electric

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actuator for out-of-plane movement of a micro-lens. The design, fabrication and preliminary testing results will be described.

2. Actuation mechanism

2.1. Structure

The schematic diagram representing the proposed piezo-electrical actuation mechanism is illustrated in Fig. 1(a). It consists of a micro-lens holding platform supported symmetrically by eight piezo-electrical actuators. The micro-lens holding rigid platform is made of 4µm thick of silicon. The piezo-electrical actuator is a beam consisting of 1.5µm thick of PZT on the top of 0.15µm thick of Pt/Ti, 1µm thick of silicon dioxide, and 4µm thick silicon. It is driven a set of inter-digitated 0.15µm thick Pt/Ti top electrodes. The 900µm long piezo-electrical actuator is connected to the micro-lens holding frame through a 600µm long 4µm thick silicon 'connector' beam.

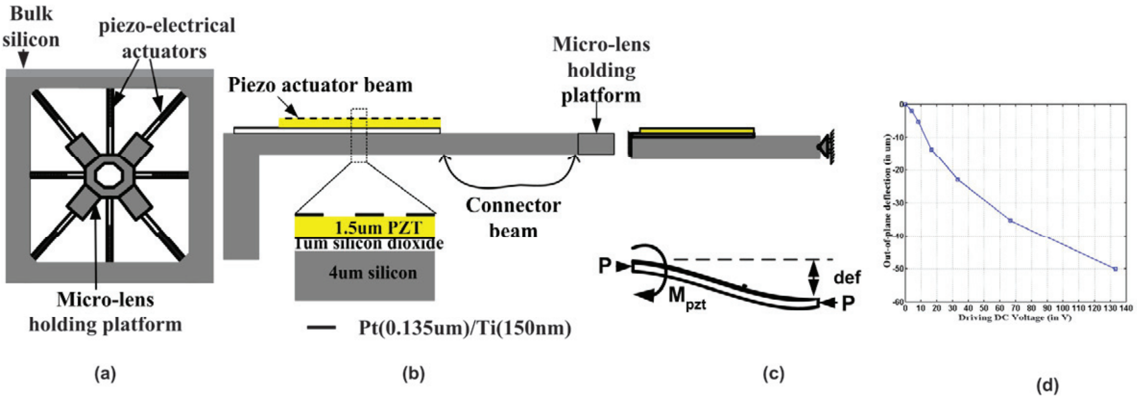


Fig 1: (a) Schematic diagram of the proposed actuation mechanism; (b) cross section view of the actuator; (c) actuator modeling and principle of operation; (d) out-of-plane deflection versus driving voltage as obtained from ANSYS simulation

2.2. Principle of operation

The actuation mechanism can be modeled as shown in Fig. 1(c), where the piezo-electrical actuator is attached to the substrate at one end and the 'connector' beam at another. The other end of the 'connector' beam is guided to move only in out-of-plane direction. Assuming that the actuator beam is initially in a flat position, and the PZT layer is biased in the direction of polarization, which is along the length of the beam, the PZT layer expands (operating in the d_{33} mode) to generate a moment that bends the actuator beam and causes downward out-of-plane movement. Since the beam is constrained not to move in the lateral direction, the expansion also results in an axial load as illustrated in the figure.

2.3. Design

The important design requirement for the piezo-electric beam is to choose the stresses in each layer and their thicknesses to minimize residual moment and average stress. This requirement ensures a flat beam or a beam with small out-of-plane deflection in the actuation direction so that small strains are translated into large out-of-plane movements. The residual stresses of each layer were measured and are given in Table 1. Using these stress values, and fixing the thicknesses of PZT at 1.5µm and Pt/Ti at 0.15µm, the oxide thickness of 1µm and silicon of 4µm are found to provide small residual moment and minimum average stress.

Table 1: material properties measured and used in ANSYS simulation and design

Material properties	PZT	Pt/Ti	Silicon	Silicon dioxide
Piezo-electric coefficient	e_{31}=e_{32}=-5.8, and e_{33}=15.2	-	-	-
Young's modulus (Gpa)	75	400	170	70
Stress (Gpa)	0.2	0.88	0	-0.45

2.4. ANSYS simulation

The proposed actuation mechanism is simulated using ANSYS. The material properties used for the simulation are provided in Table 1. Fig. 1(d) plots the simulated out-of-plane deflections of the rigid frame as a function of DC driving voltages.

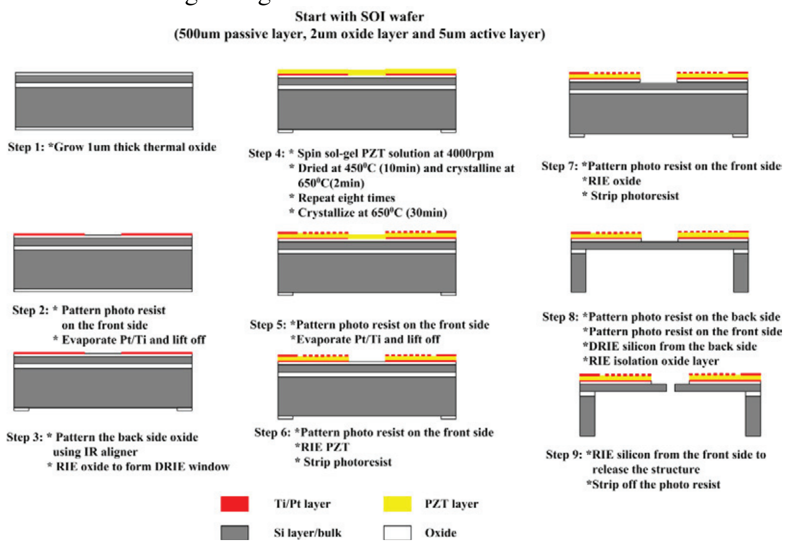
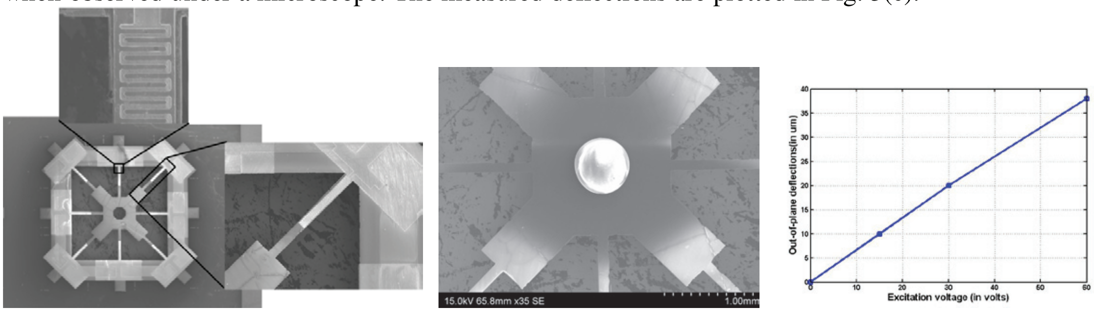


Fig. 2: Fabrication process steps

3. Fabrication and testing

The fabrication process flow is illustrated in Fig. 2. The process starts with (100) SOI wafer with 500µm thick passive bulk, 5µm thick active layer, and 2µm thick oxide isolation layers. Thermal oxide of 1µm thick is first grown on both sides of the wafer. The front side (active layer) is then patterned with 2µm thick photo-resist and evaporated with Pt(1350nm)/Ti(150nm) bi-layer, which is subsequently lifted off in NMP solution. This Pt/Ti layer is used to pattern the oxide on the backside using an Infra-red aligner. The patterned oxide is etched by RIE. After stripping the photo resist mask from the oxide, sol-gel PZT solution is spinned, baked, and crystallized on the front side. These steps are repeated eight times to obtain the desired 1.5μm thickness. The final PZT film is crystallized at 650°C for 30min. It is, then, patterned and followed by evaporation of the Pt/Ti layer, which is lifted off to form the top inter-digitated electrodes. After the definition of the electrodes, the PZT is re-patterned and RIE etched using the photo resist as a mask in CF_4 and Ar chemistry. The partial pressure of Ar and RF power are increased to improve the selectivity of PZT over the photo resist mask, and the etch rate of the PZT. The exposed silicon dioxide is subsequently RIE etched in CHF_3 and Ar chemistry to open up the silicon layer underneath. At this stage, the PZT film is poled by applying 40VDC for 30min. This is followed by DRIE of silicon from backside to expose the isolation oxide layer, which is then removed by RIE. The structure is finally released by RIE silicon from the front side.

The SEM of the successfully fabricated actuator is shown in Fig. 3(a). After fabrication, a 600μm glass microsphere ball lens is mounted onto the micro-lens holding platform using a micro-positioner and pneumatic grab and drop mechanism. The glass microsphere ball lens is secured to the lens holding platform are glued by a thin photo resist layers applied to the lens holding platform. Fig. 3(b) depicts the lens mounted on the platform. The actuation mechanism is tested by applying various DC voltages, and estimating the corresponding out-of-plane movements from the change in the location of the focal plane when observed under a microscope. The measured deflections are plotted in Fig. 3(c).



(a) (b) (c)

Fig 3: (a) SEM of the fabricated actuation mechanism; (b) micro-ball lens mounted on the lens holding frame ; (c) measured out-of-plane deflections versus driving voltage.

4. Conclusion

A piezo-electrically driven actuation mechanism for a micro-lens out-of-plane movement is demonstrated in this paper. It consists of micro-lens holding platform symmetrically supported and actuated by eight piezo-electrically driven actuators. The mechanism is designed, simulated, and fabricated. Micro-ball lens is mounted on the lens holding frame and tested. The mechanism produces about 37μm deflection at 60VDC. The voltage can be further lowered by reducing inter-digitated spacing of the top electrodes.

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